

Central engine afterglow of Gamma-ray Bursts

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Abstract. Before 2004, nearly all GRB afterglow data could be understood in the context of the external shocks model. This situation has changed in the past two years, when it became clear that some afterglow components should be attributed to the activity of the central engine; i.e., the *central engine afterglow*. We review here the afterglow emission that is directly related to the GRB central engine. Such an interpretation proposed by Katz, Piran & Sari, peculiar in pre-*Swift* era, has become generally accepted now.

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TWO KINDS OF GRB AFTERGLOWS

In the context of standard fireball model of Gamma-ray Bursts (GRBs), the prompt γ -ray emission is powered by internal shocks and the afterglow emission arises due to external shocks (see [21] for a review). In the pre-*Swift* era, most of the afterglow data was collected hours after the prompt γ -ray emission. These data was found to be consistent with the external forward shock model, though at times energy injection, a wind medium profile, or a structured/patchy jet were needed. We call the emission relevant to the external shocks generated by the GRB remnant as the “*fireball afterglow*” or “*afterglow*”. An alternative possibility for the production of the afterglow is a continued activity of the central engine (i.e., the *central engine afterglow*) via either the “internal shocks” or “magnetic dissipation”. This idea has been put forward by Katz, Piran & Sari already in 1998, shortly after the discovery of the afterglow of GRB 970228. However, the agreement of the predictions of the external shock afterglow model [24] with most subsequent multi-wavelength afterglows observation strongly disfavors the *central engine afterglow* interpretation.

One disadvantage of the central engine afterglow model is its lack of predictive power. The fireball afterglow model, instead, has predicted smooth light curves and in particular the intrinsic relation between the flux in different bands (e.g., [24]) as well as between the spectral slopes and the temporal decay. In 2003, it was already clear that in the case of a fireball afterglow, the variability timescale of the emission δt divided by the occurrence time t has to be in order of 1 or larger [19]. A highly relevant constraint is that the decline of the fireball afterglow emission can not be steeper than $t^{-(2+\beta)}$, (where β is the spectral index) unless the edge of the GRB ejecta is visible. This is because the GRB outflow is curving and emission from high latitude (relative to the observer) will reach us at later

times and give rise to a decline shallower than $t^{-(2+\beta)}$ [11, 17]. These limitations do not apply, of course to a central engine afterglow (see Fig.1).

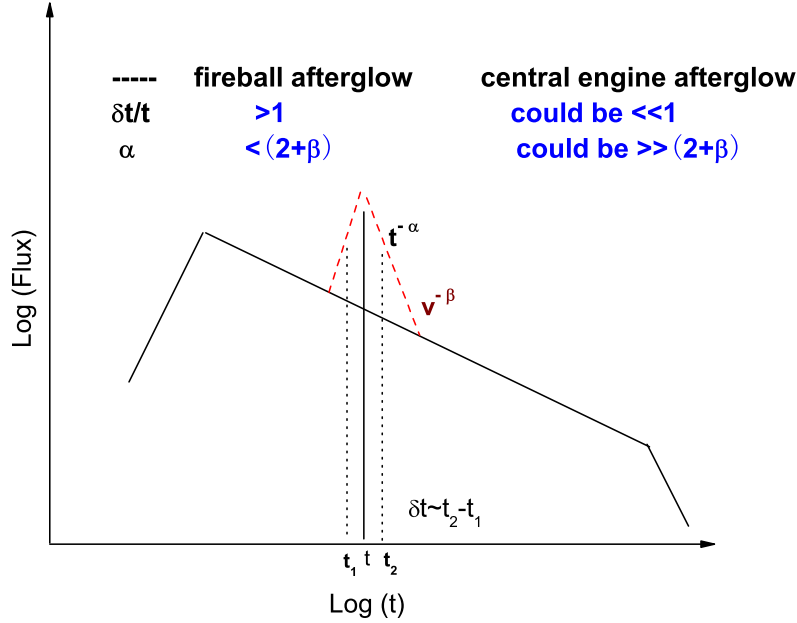


FIGURE 1. Two constraints that help us to distinguish between the *central engine afterglow* and the *fireball afterglow*.

POSSIBLE CANDIDATES OF CENTRAL ENGINE AFTERGLOW

Very early rapid X-ray decline. If the central engine does not turn off abruptly, its weaker and weaker activity will give rise to rapidly decaying emission [9]. This model can account for some very early rapid X-ray declines identified by the *Swift* satellite [1], in particular those decay with time more slowly than $t^{-(2+\beta)}$, for which the high latitude emission interpretation [29] is invalid.

X-ray/optical flares. In 1998, Piro et al. reported a late-time outburst of the X-ray afterglow of GRB 970508 from BeppoSAX. The authors attributed such an outburst to the re-activity of the central engine. However, refreshed shocks (produced by slowly moving matter that was ejected more or less simultaneously with the faster moving one during the onset of the prompt emission) can reproduce the multi-wavelength outburst as well [20]. So it is not a good *central engine afterglow* candidate. In 2005, Piro et al. [23] published an analysis of the X-ray data of GRB 011121, in which two X-ray flares after the prompt γ -ray emission are evident. They have interpreted the X-ray flares, in particular the first one, as the onset of the forward shock emission. Fan & Wei [9] applied the *decline argument* to these flares and suggested a central engine origin. Many

other possibilities like a reverse shock, a density jump, a patchy jet, energy injection and a refreshed shock have been convincingly ruled out [29].

The XRT onboard *Swift* confirmed Piro et al.'s discovery [3]. By now X-ray flares have been well detected in $\sim 40\%$ Swift GRBs. Most of these flares violate the two constraints of the fireball afterglow (e.g., [4]). Though the physical processes powering these delayed X-ray bursts are not clear yet, it is most likely that they are related to a re-activity of the central engine, i.e., they are *central engine afterglow*.

In a few bursts, optical flares have been detected (e.g., [2]) and those may also have a central engine origin [27]. But in most bursts, the very early X-ray and optical emission are not correlated (e.g., [18]). This is a natural result if the X-ray emission is dominated by the central engine emission component while the central engine optical emission has been suppressed by the synchrotron self-absorption, as suggested by Fan & Wei [9].

Power-law decaying X-rays. The temporal behavior of the flaring X-rays are quite similar to that of the prompt γ -rays. It is thus reasonable that the flares and the prompt GRB have a common origin. However, it is somewhat surprising to note that even some power-law decaying X-ray light curve might be a *central engine afterglow*. A good example is the afterglow of GRB 060218. The inconsistency of the X-ray afterglow flux with the radio afterglow flux and the very steep XRT spectra support here the central engine afterglow hypothesis [8, 25]. So far, there are two more candidates GRB 060607A [18] and GRB 070110 [26]. Both events are distinguished by a very sharp X-ray drop in the afterglow phase, which is inconsistent with the fireball afterglow interpretation [15, 26]. This is in particular the case for GRB 070110 because the optical data simultaneous with the X-ray drop does not steepen at all. For GRB 060607A, the constraint is less tight because the late-time optical light curve is unavailable.

The long lasting X-ray afterglow flat segment before the sharp X-ray drop (both its luminosity and timescale) is well consistent with the emission powered by the magnetic dissipation of a millisecond magnetar wind, as suggested by Gao & Fan [12]. Of course, additional independent signature, like a high linear polarization, is needed before the magnetar wind dissipation model can be accepted.

DISCUSSION

In contrast to what was believed in the pre-*Swift* era, it is evident now that the role of the central engine has to be taken into account when interpreting many *Swift* GRB afterglows. The “ad hoc” hypothesis made in Katz et al. [16] has been well confirmed. The chromatic behavior of the afterglow suggests that the afterglow in X-ray and in lower energy bands may have a different origin [9]. This can be easily understood if the synchrotron self-absorption is strong enough to suppress the central engine optical emission but not the X-rays [9]. Recently, Ghisellini et al. [13] adopted this idea to interpret the chromatic break of the early optical and X-ray data of some *Swift* GRBs [6] and argued these shallowly decaying X-ray emission are *central engine afterglow*.

The fruitful *Swift* early afterglow observations open a new window to reveal the behavior of the central engine. The continued activity of the GRB central engine is now a well-established fact. But the underlying physical processes are less clear. Among the various models put forward (see [28] for a review) fallback accretion onto the

nascent black hole may be the most natural one. Other models involve the magnetic activity of the central engine [10, 5, 12]. Such models might be tested by a polarimetry as in magnetic energy dissipation scenarios one can expect the emission to be highly polarized. Alternatively if the shocks powering the X-ray *central engine afterglow* (the flares or some power-law decaying light curves) are not significantly magnetized the synchrotron-self Compton (SSC) emission will peak in the GeV energy band and it may be strong enough to be detected by the upcoming GLAST satellite (e.g., [7]). Such emission might have been already observed in the long-lasting shallowly decaying GeV afterglow emission of GRB 940217 [14]. This might have been the SSC component of the central engine X-ray flat segment as that detected in GRB 070110. If it is the case, a rapid GeV emission drop simultaneous with that in X-ray band, will be present. Our interpretation thus can be tested in the near future directly by the cooperation of *Swift* and GLAST.

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